Defense Threat Reduction Agency
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DTRA-TR-17-10

TECHNICAL REPORT

Intense Terahertz Fields for Fast Energy Release

Distribution Statement A. Approved for public release; distribution is unlimited.

November 2016

HDTRA1-12-1-0044

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14. ABSTRACT
A fundamental research program of combined shock loading and intense terahertz-frequency (THz) irradiation of energetic materials was supported. The program has high risk since the effects of high THz fields on shocked energetic materials or shocked materials of any kind were entirely unexplored. The program has potential for high payoff in the form of fundamental discovery that could be exploited for greatly accelerated release of chemical energy stored in energetic materials. Support for the program was ended prematurely and the potential benefits were not realized.

15. SUBJECT TERMS
energetic materials, shock loading, terahertz fields, THz

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UNIT CONVERSION TABLE

U.S. customary units to and from international units of measurement*

U.S. Customary Units	Multiply by → ← Divide by†		International Units
Length/Area/Volume			
inch (in)	2.54	$\times 10^{-2}$	meter (m)
foot (ft)	3.048	$\times 10^{-1}$	meter (m)
yard (yd)	9.144	$\times 10^{-1}$	meter (m)
mile (mi, international)	1.609 344	$\times 10^{3}$	meter (m)
mile (nmi, nautical, U.S.)	1.852	$\times 10^{3}$	meter (m)
barn (b)	1	$\times 10^{-28}$	square meter (m^2)
gallon (gal, U.S. liquid)	3.785 412	$\times 10^{-3}$	cubic meter (m^3)
cubic foot (ft^3)	2.831 685	$\times 10^{-2}$	cubic meter (m^3)
Mass/Density			
pound (lb)	4.535 924	$\times 10^{-1}$	kilogram (kg)
unified atomic mass unit (amu)	1.660 539	$\times 10^{-27}$	kilogram (kg)
pound-mass per cubic foot (lb ft^{-3})	1.601 846	$\times 10^{1}$	kilogram per cubic meter (kg m^{-3})
pound-force (lbf avoirdupois)	4.448 222		newton (N)
Energy/Work/Power			
electron volt (eV)	1.602 177	$\times 10^{-19}$	joule (J)
erg	1	$\times 10^{-7}$	joule (J)
kiloton (kt) (TNT equivalent)	4.184	$\times 10^{12}$	joule (J)
British thermal unit (Btu) (thermochemical)	1.054 350	$\times 10^{3}$	joule (J)
foot-pound-force (ft lbf)	1.355 818		joule (J)
calorie (cal) (thermochemical)	4.184		joule (J)
Pressure			
atmosphere (atm)	1.013 250	$\times 10^{5}$	pascal (Pa)
pound force per square inch (psi)	6.984 757	$\times 10^{3}$	pascal (Pa)
Temperature			
degree Fahrenheit (^{o}F)	$[T(^{o}F) - 32]/1.8$		degree Celsius (^{o}C)
degree Fahrenheit (^{o}F)	$[T(^{o}F) + 459.67]/1.8$		kelvin (K)
Radiation			
curie (Ci) [activity of radionuclides]	3.7	$\times 10^{10}$	per second (s^{-1}) [becquerel (Bq)]
roentgen (R) [air exposure]	2.579 760	$\times 10^{-4}$	coulomb per kilogram (C kg^{-1})
rad [absorbed dose]	1	$\times 10^{-2}$	joule per kilogram (J kg^{-1}) [gray (Gy)]
rem [equivalent and effective dose]	1	$\times 10^{-2}$	joule per kilogram (J kg^{-1}) [sievert (Sv)]

*Specific details regarding the implementation of SI units may be viewed at http://www.bipm.org/en/si/.
†Multiply the U.S. customary unit by the factor to get the international unit. Divide the international unit by the factor to get the U.S. customary unit.

Grant # HDTRA 1-12-1-0044

Intense Terahertz Fields for Fast Energy Release

Final Report

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Summary of Project

The project had the ambitious objective of subjecting energetic materials to two types of dynamic stimuli: laser-generated shock and laser-generated strong-field THz fields. The underlying hypothesis was that the rate of energy release under shock loading might be accelerated by the additional action of the THz fields which could liberate and accelerate electrons to multi-eV energies that would break chemical bonds.

The project was planned for a five-year period with an initial period of three years followed by an optional two-year additional period.

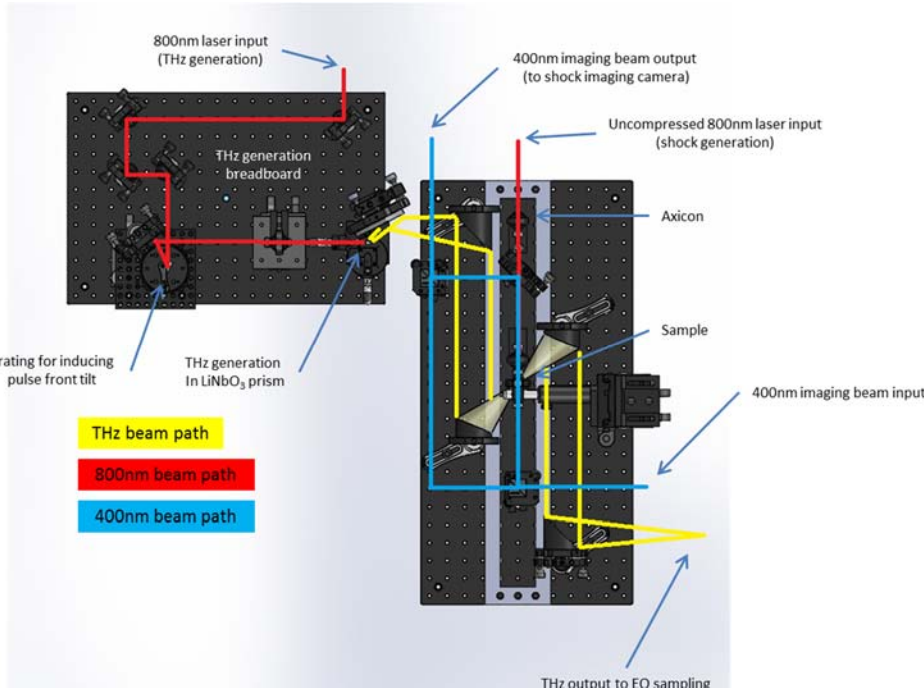
Activities during the grant period

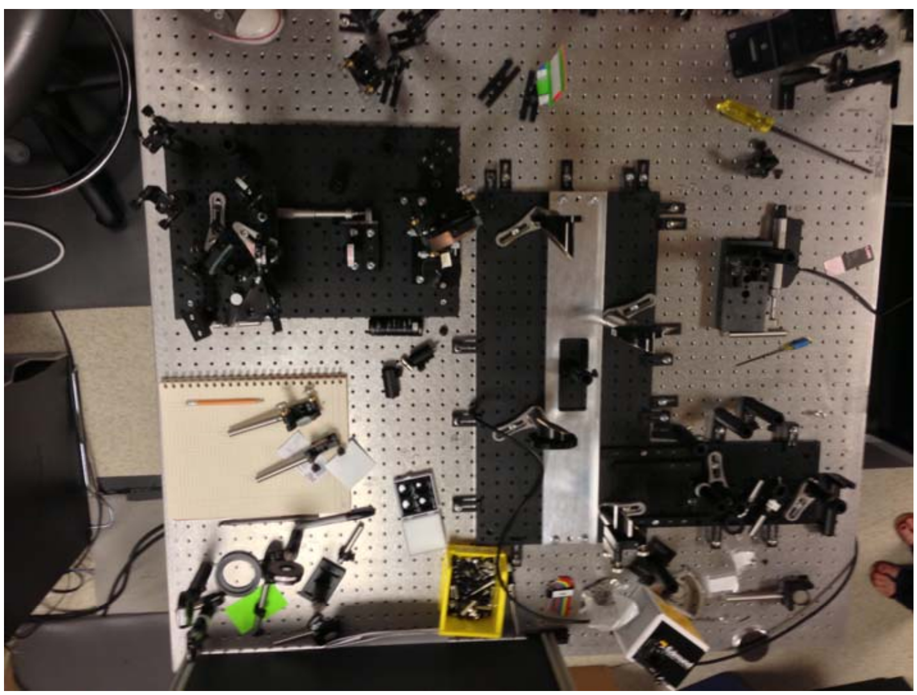
At the start of the project in 2012, both of the methods for producing dynamic stimuli were themselves only recently developed. The laser shock was to be generated by a method first reported in 2011 in which a circular "ring" pattern of pulsed laser light is absorbed in a thin (~ 10 μm thick) sample layer to launch a focusing shock wave. The shock propagates within the quasi-2D layer and focuses at the center of the circular excitation pattern. The sample can be a polymer layer with embedded crystallites of RDX or other energetic materials, and the shock pressure at a crystal at the focus can reach more than 20 GPa, far exceeding the level needed to initiate partial chemical and physical decomposition.

We demonstrated laser generation of single-cycle THz pulses with microjoule energies in 2007, and we demonstrated THz-induced nonlinear responses in a variety of material in the ensuing years. This included strongly nonlinear responses including electronic and structural phase transitions generated by THz liberation and acceleration of carriers. These results led to our hypothesis that a similar mechanism could enable THz initiation of chemical and physical decomposition of energetic materials under shock loading. The disruption of the energetic crystal lattice upon shock loading would ensure that many electrons would reside in shallow traps at crystal interfaces and defects, and these could be liberated easily by the THz field and accelerated to multi-eV energies sufficient to break chemical bonds in RDX or other energetic materials.

The main effort in the project was to combine both of the newly developed dynamic stimuli in a single experimental system, along with the diagnostics that could allow us to monitor shock propagation in the sample and observe any effects of THz irradiation. In order to optimize the system, we moved a high-power femtosecond amplifier from a different lab into the lab with the experimental setup. Its output, up to 30 mJ in a femtosecond pulse, was sufficient to be split for generation of both the shock and the THz pulse and for probing of the sample under the influence of both dynamic stimuli. We also interfaced a multi-frame camera that could record up to 16 images during a single shock loading event. The laser amplifier and the multi-frame camera were both obtained from earlier or concurrent ONR DURIP projects, with a total value of about $2/3M. This major influx of equipment from other projects made possible the assembly of an integrated experimental system for subjecting an energetic crystalline sample to shock and THz dynamic stimuli and observing the consequences in real time as they occurred.

The central part of the integrated experimental system is shown below. The schematic illustration and photo do not include the laser system that produces the THz and shock stimuli or the camera that records the sample responses.





Work was also conducted to optimize the sample assembly for access for the laser light needed to generate the shock and to monitor the response and access for the THz light needed to simultaneously irradiate the sample. Preliminary measurements of sample responses to each of the stimuli were recorded.

Unfortunately the optional two-year funding period was not approved so the planned measurements of nonlinear sample responses to the combined dynamic stimuli were not carried out. We have since made significant progress in applying each of the stimuli separately and measuring the responses of RDX and other energetic materials to them. We are hoping to measure responses to the combined stimuli as well.

Significance of Results

The project laid the groundwork for testing a novel hypothesis about highly nonlinear responses of energetic materials to the combination of focusing laser-driven shock and THz strong-field dynamic stimuli. Since the end of the project we have seen dramatic responses of RDX to each of these stimuli separately and we have recorded multi-frame camera images showing RDX time-dependent decomposition following laser-shock loading. We remain hopeful that the integration of shock and THz dynamic stimuli will result in extreme acceleration of energy release kinetics from energetic materials.

Publications

There were no publications resulting from the grant.

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